Earth Science Enterprise Technology Planning Workshop

Ultra-High Data Rate Communications

Kul Bhasin (Co-Chair) - GRC
Glenn Prescott (Co-Chair) - NASA HQ
Faiza Lansing (Facilitator) - JPL

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Earth Science Enterprise Technology Planning Workshop

Ultra-High Data Rate Communications

Agenda

New Millennium Program and UHDR	Faiza Lansing	NMP/JPL
UHDR Overview	Kul Bhasin	GRC
Science Perspective/Hyperspectral Imaging	WarrenWiscombe	GSFC
Communications Outlook for NASA's Earth Science Enterprise	Charles Wende	NASA/HQ/YF
UHDR for SAR	Bernard Minster	UCSD
High Data Rate Communications	Keith Wilson	JPL
Space Communications Technology at Glenn Research Center	James Budinger	GRC
Communications Technology at Goddard Space Flight Center	Ron Parise	GSFC
Communication Trends & Future Data Rate Requirements	Richard Kocinski	Lockheed Martin
Optical Communication Systems	Roy Nelson	Ball Aerospace
Direct Data Distribution (D^3) Overview	Lawrence Wald	GRC
UHDR Communications	Cathy Freeman	EMS Technologies
K/Ka-Band Satellite Transmit Antenna for D^3 and Leo Satellites	Dennis Kershner	Raytheon
UHDR Communications using Laser Crosslinks	Calvin Abplanap	Eastman Kodak
High Temperature Superconducting Sub-Systems for Space Communications	Joseph Warner	GRC
UHDR (Oral Comments)	Andrew Keys	MSFC
An Inflatable Antenna For UHDT Communications	Ron Schulze	JHU/APL
Interim Summary of Issues		
Mid-Term Session Summary		
Identify Technology Gaps and		
Develop Technology Roadmap		
Complete Technology Roadmap		
Requirements and Justifications		

Earth Science Enterprise Technology Planning Workshop
Ultra-High Data Rate Communications

Participants

Abplanalp, Calvin	Kodak	Lesh, Jim	NASA - JPL/9700
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Enlow, David	Lockheed Martin Space	Savage, Robert	NASA - GSFC/500.0
Faithorn, Lisa	NASA - ARC/RIACS	Schulze, Ron	John Hopkins Univ./APL
Fuhrman, Nick	EMS Technologies	Silverman, George	Lockheed Martin
Gray, Andrew	NASA - JPL/3310	Sroga, Jeff	Lockheed Martin
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Huang, Marshall	TRW	Wachowicz, M.	Wageningen UR
Kershner, Dennis	Raytheon	Wald, Lawrence	NASA - GRC/6150
Keys, Andrew	NASA - MSFC/SD72	Warner, Joe	NASA - GRC/5620
Koconski, Rick	Lockheed Martin	Wende, Charles	NASA - HQ/YF
Lansing, Faiza	NASA - JPL/NMP	Wilson, Keith	NASA - JPL/3310

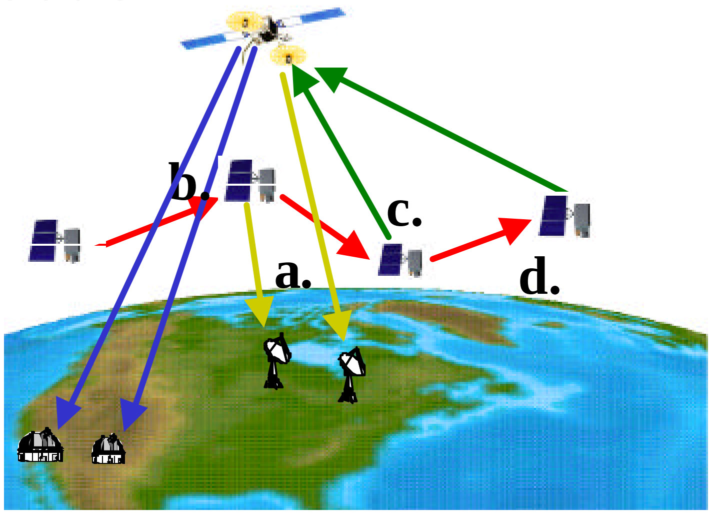
Specific Capability Needs for Each Measurement Class As Determined by the Scientific Community

Instruments / Class / Needs	Hyperspectral Land Imaging	Radar Imaging	Lidar Imaging	Scatterometers	TOMS	Multi-Instrument Platform
High Data Volume	✓	✓				✓
Low Data Volume					✓	
Real Time Applications	✓	✓	✓			✓
Constellations	✓	✓	✓	✓	✓	✓

Earth Science Missions: Peak Data Rates Needs

Types of links

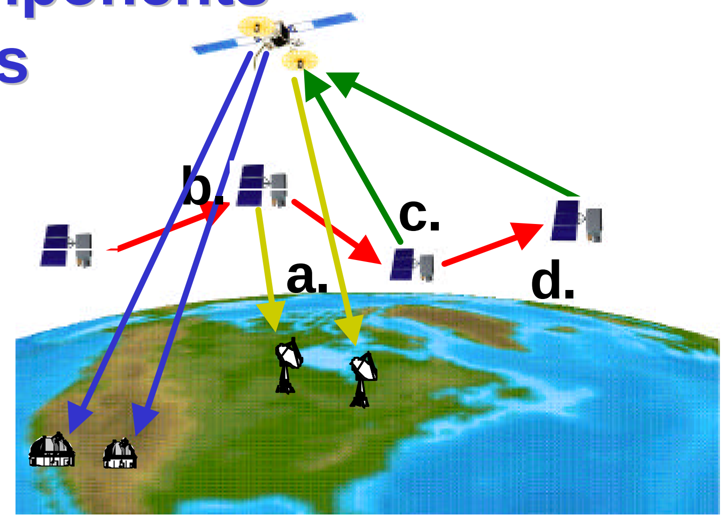
a. Data Distribution (DD) from LEO Spacecraft (Spacecraft to ground)
b. DD from GEO spacecraft
c. LEO to GEO relay
d. Multi-spacecraft links
e. Sensor Webs



Types of Links	State-of-the-Practice	2010	2015	2020
a. DD from LEO Spacecraft	X-Band 150 Mbps	10 Gbps gateway 1 Gbps D/L	25 Gbps	100 Gbps
b. DD from GEO spacecraft	150 Mbps	10 Gbps	25 Gbps	100 Gbps
c. LEO to GEO relay	2 Mbps	150 Mbps 1 Gbps		
d. Multi-spacecraft links	4 Mbps	45 Mbps	155 Mbps	N/A
e. Sensor Webs	100 bits/sec (gnd sensor to sc)	Multiple links of A, B, C, D	Multiple links of A, B, C, D	Multiple links of A, B, C, D

*** The current X-band capability is limited up to 300 Mbps due to spectrum allocations**

Major Technology Components and TRL Levels



Types of links

a. Data Distribution (DD) from LEO Spacecraft (Spacecraft to ground)
b. DD from GEO spacecraft
c. LEO to GEO relay
d. Multi-spacecraft links
e. Sensor Webs

Types of Links	State-of-the-Practice	Future Technology Capabilities	Technology Components for Space Segment	TRL
a. DD from LEO Spacecraft	X-Band	Ka-Band and Optical	Phased array antennas Acq/Trk (Optical) High Power/BW Lasers	3 - 5
b. DD from GEO spacecraft	Ku-Band and X-Band	Ka-Band and Optical	Large reflector antennas Acq/Trk (Optical) High Power/BW Lasers	3 - 5
c. LEO to GEO relay	S-Band and Ku-Band	K-Band and Optical	Agile reconfig. Antennas Low-noise receivers High E transmitters Acq/Trk (Optical) High Power/BW Lasers	3 - 5
d. Multi-spacecraft links	UHF	UHF to W-Band and Optical	Multibeam antennas Acq/Trk (Optical) High Power/BW Lasers Mini mixed ckt components	3 - 5
e. Sensor Webs (ES Vision)	None	All of Above for physical layer. Higher layer technologies	All of the Above	

Validation Plans for Ultra-High Data Rate Optical Communications

Flight Validation Rational

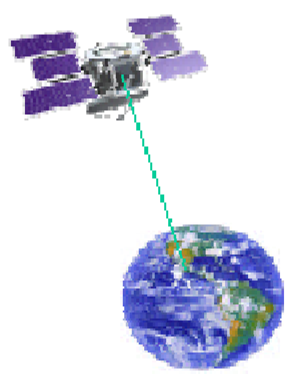
•Major Implementation Shift
•Validation of the most critical subsystem is possible only from space:
  –Acquisition, tracking and fine-pointing of laser beam over very large distances
  –Effects of (non-horizontal path) atmospheric phenomenon on the downlink and uplink laser beams and over very large distances

Justification

•Offers high bandwidth communications
  - Provide near real-time video
  - Provide better resolution of image
  - Detect and characterize events that might occur on planetary bodies or on our Earth and its surrounding atmosphere.

Accommodation Requirements

• Power 265 Watts/beam
• Volume: 1000 cm3
• Mass<2 kg



Top-Level Development and Flight Schedule

- A 2.5Gbps data-rate experiment
  - from a 10-cm aperture terminal onboard the Space-Station
  - to a 1-m telescope on Earth is planned for October '03 launch.
  - precursor to a future facility onboard the International Space station.
- A flight validation on a NMP Mission
  - 2004-2005

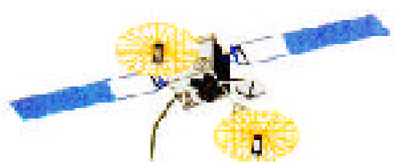
Validation Plans for Ultra-High Data Rate Radio Frequency Communications

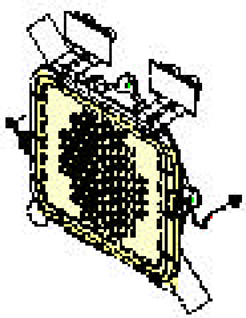
Future Feasibility Studies

- W & V-Band/ Tera-Hertz Communications
  - Identify the need
  - End-to-end System architecture
  - Ground support system
  - Reliability in space environment
  - On-board processing and data compression
  - Candidate projects

Justification

- An RF communications system will provide:
  - Familiar/proven technology
  - Miniaturization, smaller mass and volume
  - Modifying existing Ground Stations form Ka-Band to higher frequencies
  - Reduce power consumption, which will affect power subsystem





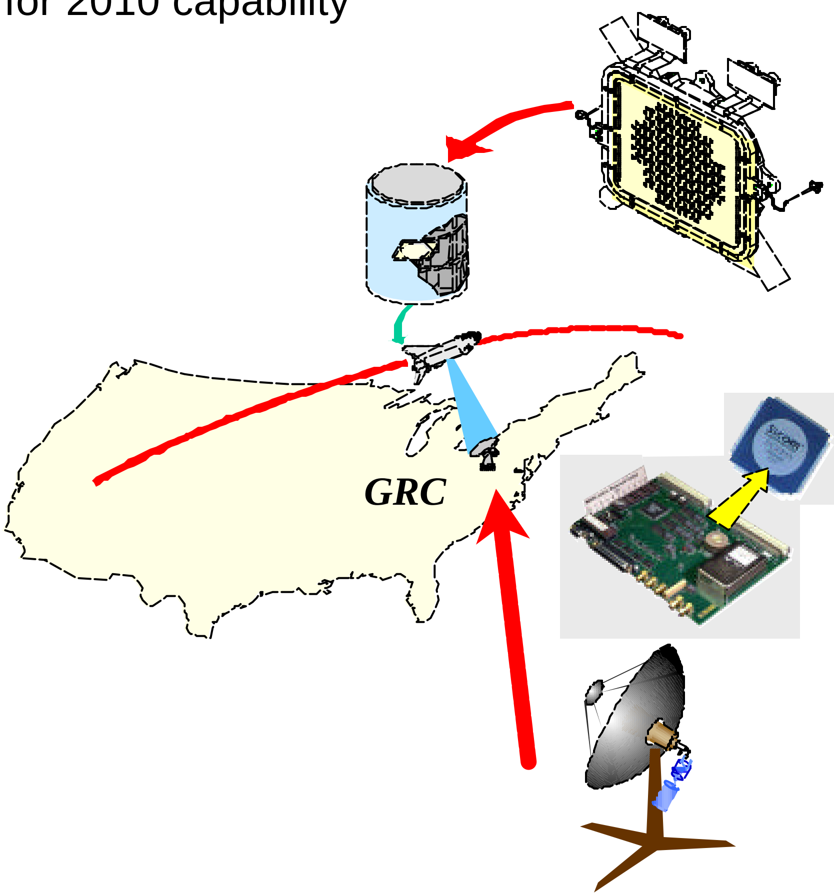
Top-Level Development and Schedule

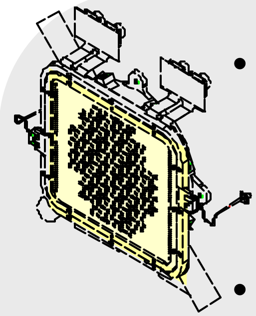
- Feasibility Study 2001-2002
- Component development 2002-2004.
- Breadboard 2004-2006
- Engineering Model 2006-2008
- Flight Hardware 2010

Ultra-High Data Rate Radio Frequency Communications On-Going Investments

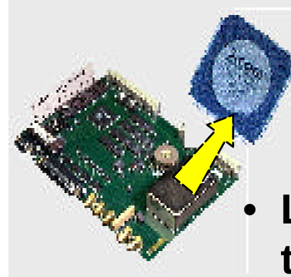
Objective

- Develop D^3 capability at 1Gbps to user (1 meter) and 10 Gbps to gateway (3.8 meter) for 2010 capability

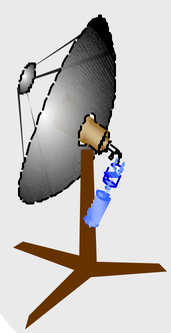




- **Ka-band, electronically-steered antennas (+/- 65º)**
  - Multi-beam MMIC based
  - Scanning reflect arrays

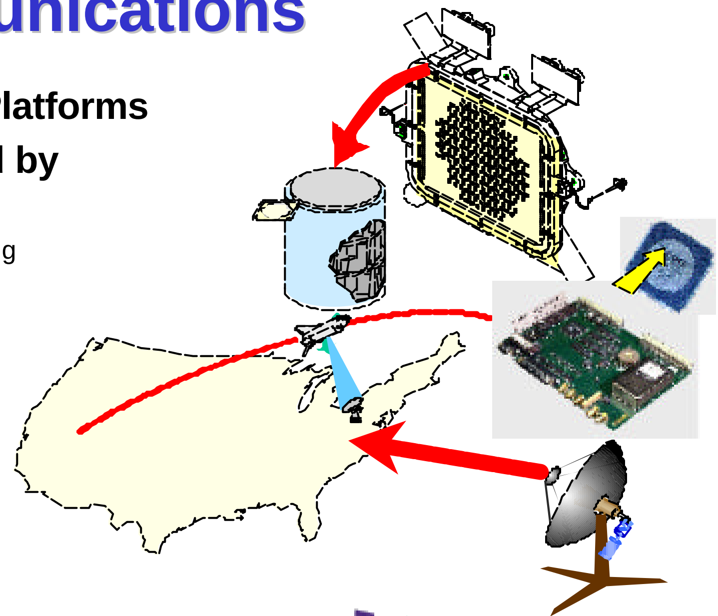


- **Bandwidth and power efficient modem/coded**
  - 3bps/Hz Bandwidth efficiency
  - 10^{-11} end-user BER
  - 622 Mbps to 12 Gpbs
  - Reduce size, mass, power by 2X
- **Low-cost, autonomous terminal (PI) 1-meter**
  - cryocooled receiver
  - open-loop tracking



- **Integrated Internet Protocol**
  - seamless ops technology

Roadmap for Ultra-High Data Rate Radio Frequency Communications



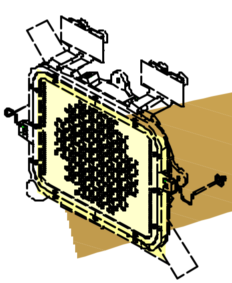
Concept: High-Rate RF Communications for LEO and GEO Platforms

- **Science Driver: Near real-time downlink of data collected by active/passive instruments in LEO and GEO links**
  - Severe storm warnings, volcanic eruptions, and other natural hazard monitoring
- **Benefits**
  - Reduce size, mass power, cost over SOP
  - Increased data rate (10x) at higher QoS (10^{-11} to 10^{-6})
  - Multiple contacts at regional and loacl (PI) sites
  - Increased availability (all weather locations)
  - Leverage commercial infrastructure
- **Rational for Flight**
  - Atmospheric effects only evaluated from space
  - No arrays at Ka-band have flown in space
  - Long-term space effects on array ane electronics (atomic O^2, radiation, micro-meteors
  - Autonomous, open loop acquisition and tracking

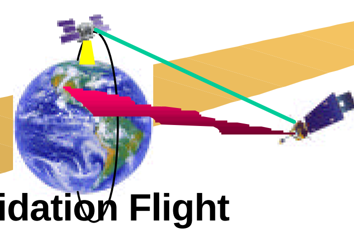
Capability

Ground Tests

- **Ka-band phased array antennas at 3.9 Mbps per Watt of prime spacecraft power**

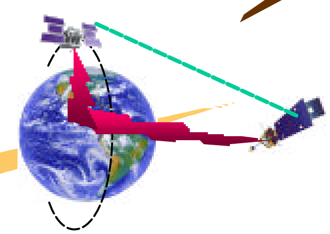


Point-to-Multipoint Communications



Validation Flight

- **Demonstrate Ka-Band phased array-based communications system for ultra-high data rate (>1Gbps)**
- **265 Watts/beam; 1000 cm3; <2 kg**
- **Dual independent beam, 622-Mbps per beam**
- **MMIC phased array system at 19GHz to multiple 1 meter terminals**



Science Mission

with point-to-multipoint communications

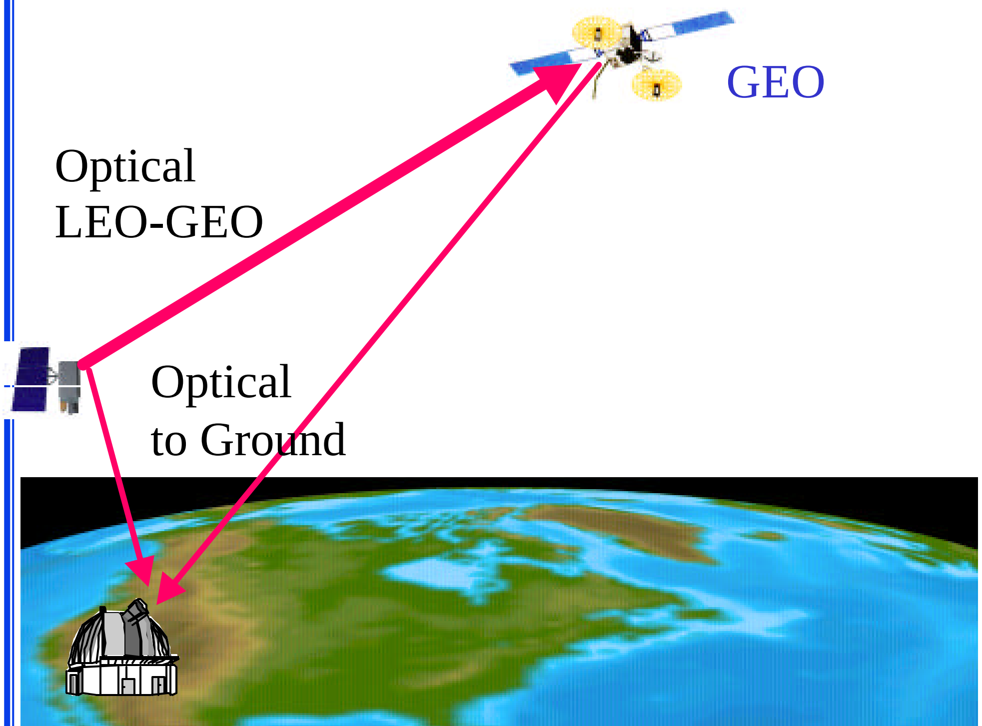
01 02 03 04 05 06 07 08

Fiscal Year

Ultra-High Data Rate, Optical Communications: On-Going Investments

Objective:
- To enable the use of optical communications systems for ultra-high data rate (>2 Gbps) communications from spacecraft to spacecraft and between spacecraft to ground

Multi-Gbps Data Rate
LEO-to-GEO Optical Communications Link



Acquisition/Tracking/Pointing
- **Algorithms**
- **Focal-Plane-Array**
- **Laser Beacons (space-based)**

Telescopes

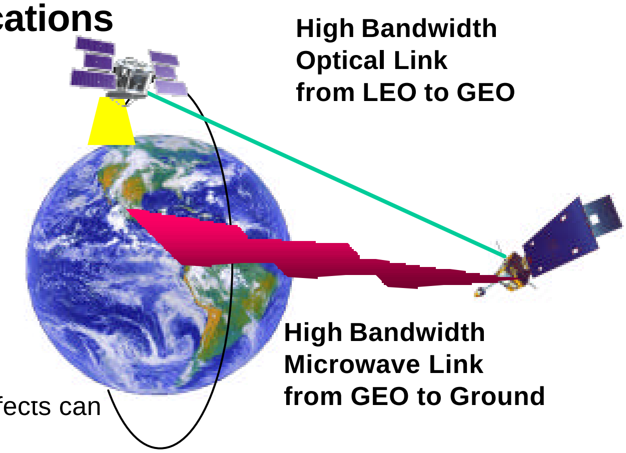
- **0.1 to 0.3 m**
- **Thermally stable**
- **High background light rejection**

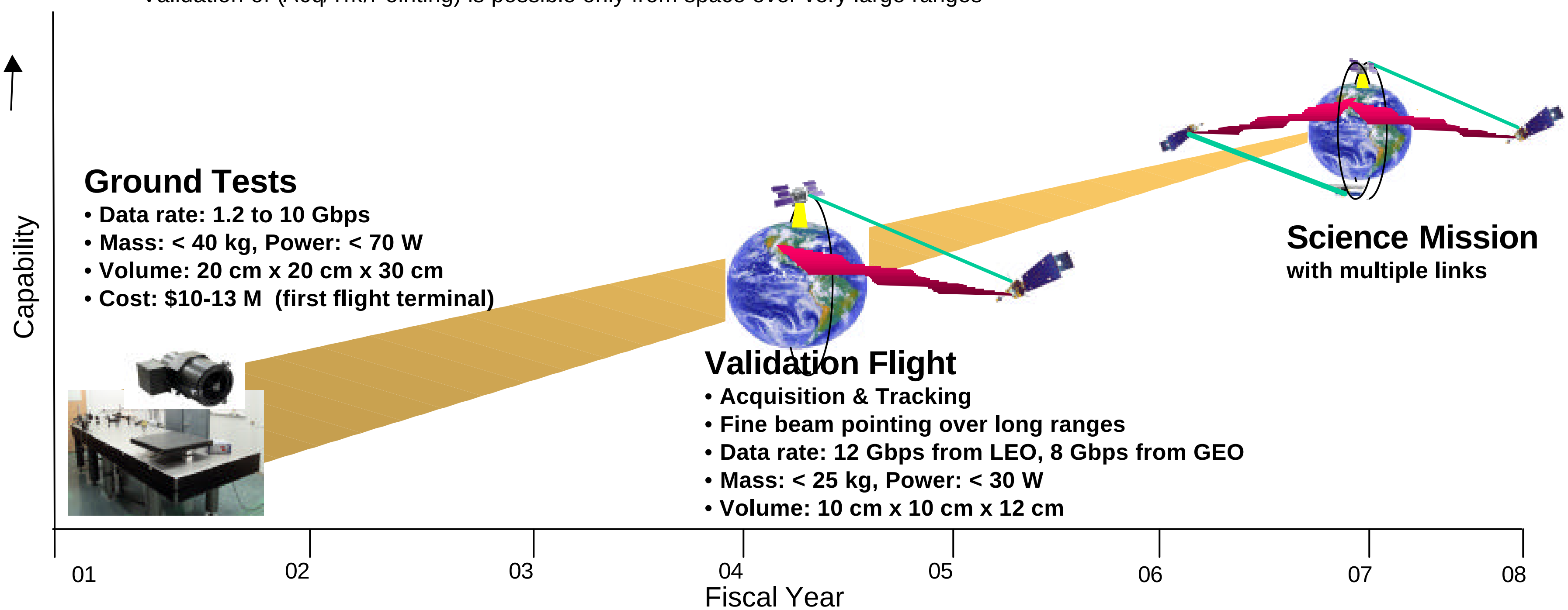
Communications
- **Modulators up to 10 Gbps**
- **1550 nm lasers**
- **Multiplexers & de-Multiplexers**
- **receivers (radiation tolerant)**

Roadmap for Ultra-High Data Rate Optical Communications

Concept: High-Rate Optical Terminals for LEO to GEO Communications

- **Science Driver:** Near real-time downlink of data collected by active/passive instruments in LEO through GEO link
  - Severe storm warnings, volcanic eruptions, and other natural hazard monitoring
- **Technology Drivers**
  - Optical Comm from LEO to GEO
    - Requires much less mass, power, and cost
    - Microwave link from GEO ground
- **Validation Rational**
  - Link availability due to cloud attenuation & other (non-horizontal path) atmospheric effects can be demonstrated only from space
  - Validation of (Acq/Trk/Pointing) is possible only from space over very large ranges





Ultra Low Noise Microwave Link From LEO to GEO Link or Earth to LEO Relay

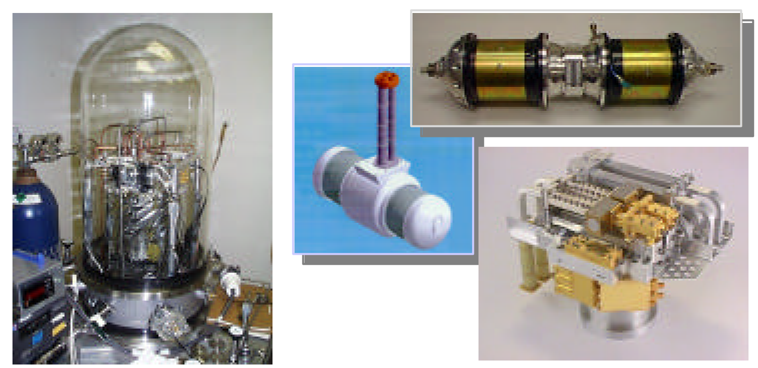
Technologies: Cryocooled receiver at Ka-band (noise temperature= 80 k)

- LEO-LEO data rate increase: 4X (or decrease transmit power requirement by 75%)
- LEO-GEO data rate increase +80% (or decrease transmit power requirement by 45%)
- Applies to data collection from
  - Earth sensors
  - Balloons
  - Planes

Validates:

- HTS RF devices
- Cryogenics for core satellite systems
- InP pseudomorphic HEMT

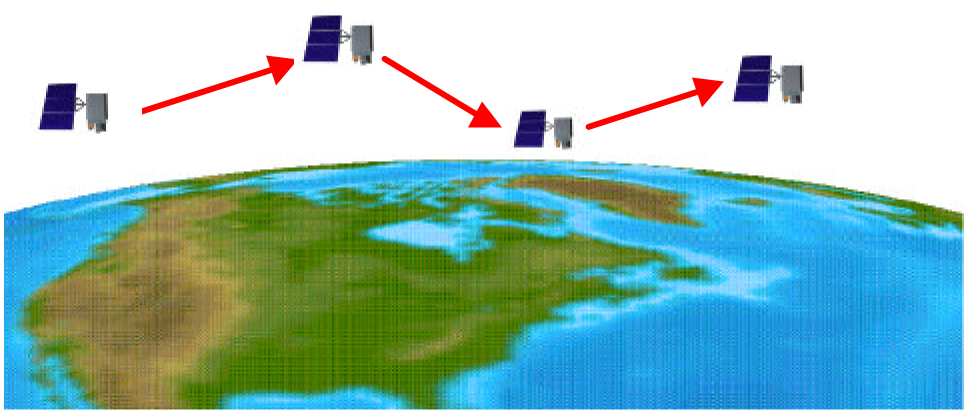
HTS Cryorecievers



Inter-Spacecraft Communications for Earth Science Constellations

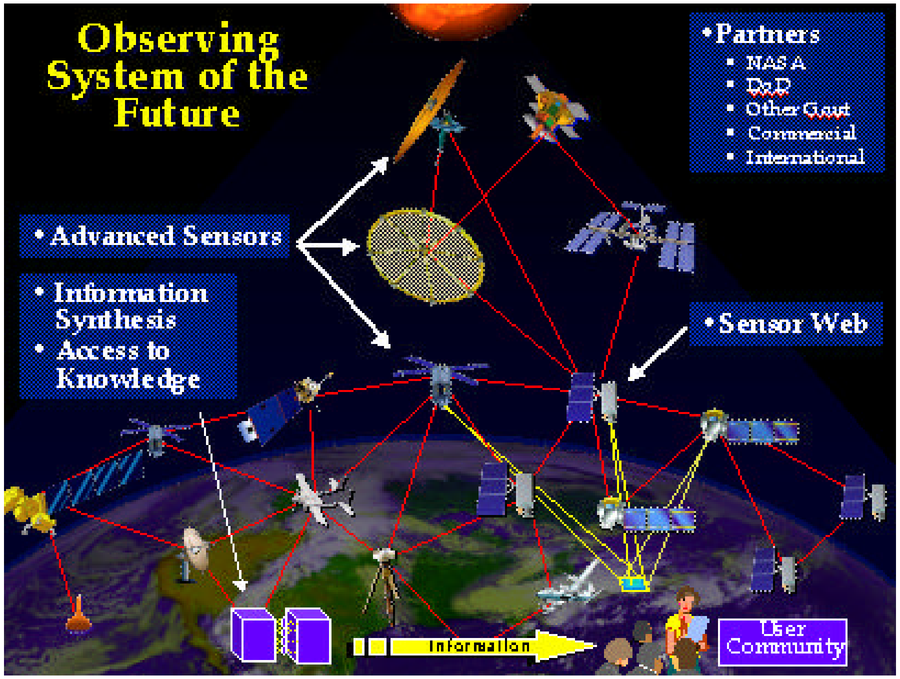
Technologies that need flight validation

- Phased array - Ka-band - 10Mbps ➲ 100Mbps ➲ Up
  - Azimuth steering - 360°, Elevation steering - ±90°
  - Relative position and attitude measurement - coarse ±1-100cm, ±0.1°-5°
- Optical - ➲ 100Mbps ➲ 1Gbps ➲ 10Gbps
  - Azimuth steering - 360°, Elevation steering - ±90°
  - Relative position and attitude measurement - fine ±1-10^6µm, ±1' - ±0.1"
- Subsystems
  - Linear LNA's
  - Modems, application specific integrated circuits (ASICs)
- Inter-spacecraft protocols
  - TDMA, CDMA, IEEE802.11, wireless IEEE1394, ?



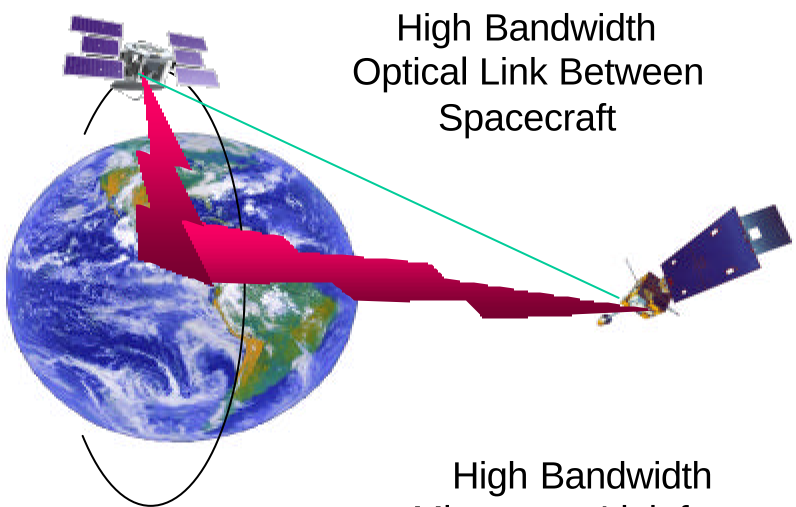
Technologies That Need Flight Validation for Sensor Web

- **Low Rate Web** (to ocean buoys, balloons, ground sensors)
  - Move up in frequency - X, Ka-band transmitter/receivers
  - Implement downlink-reconfigurable sensors
- **High Rate Web** - inter-spacecraft links between non-related spacecraft/missions to provide a high rate, general use communications network.
  - Use communications packages defined for Inter-spacecraft communications.
  - Generic network protocols
    - TDMA. CDMA, ATM, Ethernet



Potential Next Steps for Ultra-High Data Rate Communications

Five potential areas for further feasibility studies, technology development and demonstrations were identified during the breakout session to meet Earth Science needs in High Rate Data Delivery:



- High rate Ka-band microwave link technologies from LEO to Ground for > 1 Gbps data rates which requires integration of MMIC phased array, high speed modem and autonomous tracking terminals
- High rate optical link technologies from GEO to Ground for 8 Gbps
- Ultra low noise microwave link from LEO to GEO
- Inter-spacecraft communication technologies for constellations including advanced protocols
- Space Internet technologies for sensor web